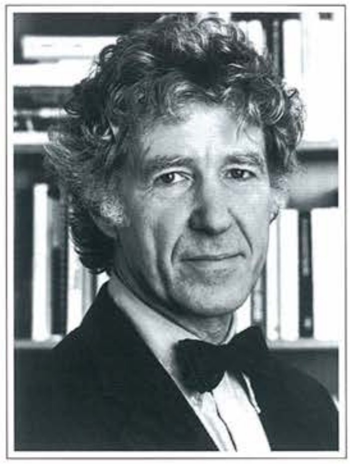
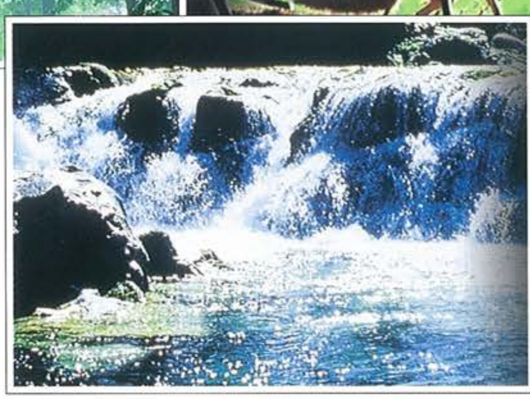
The Winners of the Blue Planet Prize
1994

1994
Blue Planet Prize

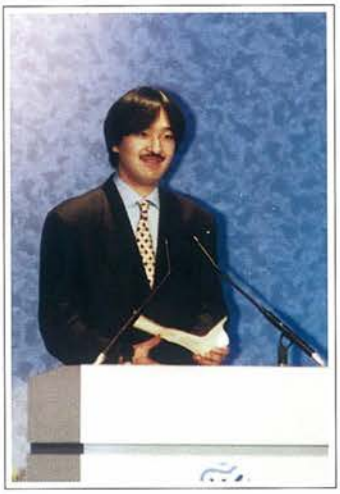
Professor Dr. Eugen Seibold (Germany)
Professor Emeritus at the University of Kiel

Lester R. Brown (U.S.A.)
Founder and President of the Worldwatch Institute





At the 1994 Blue Planet Prize awards ceremony, the slide presentation centered on the theme of the interconnectedness of life on Earth. The images depicted our planet's beauty as a rich tapestry of life woven from the green of the trees and young grass sprouts together with the insects and other animals.



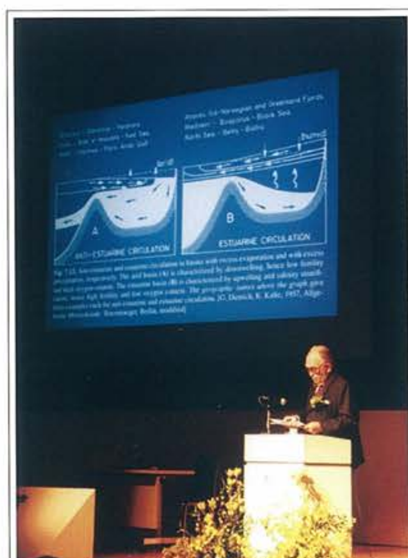
His Highness Prince Akishino delivering a congratulatory speech.

His Highness Prince Akishino and Her Highness Princess Kiko.

Lester Brown gives his speech on the Environmental Revolution—a restructuring of the global economy in line with environmentally sound practices.

Professor Jiro Kondo, chairman of the Selection Committee, explains the rationale for the determination of this year's winners.

Walter F. Mondale (left), ambassador of the United States of America to Japan, and Dr. Heinrich Dieckmann (right), ambassador of the Federal Republic of Germany to Japan, congratulating the laureates.



Dr. Seibold delivering his lecture about the influence of the sea floor on the environment.

Profile

Professor Dr. Eugen Seibold

Professor Emeritus at the University of Kiel

Education and Academic and Professional Activities

1948– Ph. D., University of Tübingen
1949–51 Assistant Professor, University of Tübingen
1951–54 Assistant Professor, Technical University of Karlsruhe
1954–58 Associate Professor, University of Tübingen
1958–79 Professor and Director, Geological-Paleontological Institute, University of Kiel
1964–70 Chairman, Geological Association (Geologische Vereinigung)
1967 Chairman, Scientific Committee on Oceanic Research (SCOR) 19th meeting on Micropaleontology, in Cambridge, U.K.
1970 Chairman, SCOR 31st meeting on Geology of the East Atlantic Continental Margin, in Cambridge, U.K.
1971 Member, Deutsche Akademie der Naturforscher, Leopoldina/Halle
1972 Member, Akademie der Wissenschaften und der Literatur, Mainz
1974 Member, Jungius Gesselleschaft der Wissenschaften, Hamburg
1974 Chairman, SCOR 37th meeting on Marine Plankton and Sediments, in Kiel
1974 Chevalier Ordre Palmes Académiques
1976 Honorary Member, Geological Society, London
1980–84 President, International Union of Geological Sciences (IUGS)
1980–85 President, Deutsche Forschungsgemeinschaft (DFG), Bonn
1982 Member, Société Géologique, France
1982 Honorary Fellow, Geological Society, U.S.A.
1982 Honorary Fellow, Geological Society, Africa
1982 Corresponding Member, Bayerische Akademie Wissenschaften, Munich
1983 Grosses Bundesverdienskreutz
1983 Honorary doctorate, Université Parisien
1984 Honorary doctorate, University of Norwich, U.K.
1985 Member, Heidelberger Akademie Wissenschaften
1985 Honorary Professor, University of Tengji, Shanghai
1986 Honorary Senator, University of Kiel
1986 Honorary Senator, University of Giessen
1987 Honorary Member, Deutsche Akademie der Naturforscher Leopoldina/Halle
1988 Member, Akademie Europaea
1989 Member, Akademie Wissenschaften, Göttingen
1989 Membre Associé Étranger, Académie des Sciences, Paris
1984–90 President, European Science Foundation (ESF), Strasbourg, France

1986– Honorary Professor, University of Freiburg
1994 Member, Kroatian Akademie Wissenschaften
1994 Asahi Glass Foundation Blue Planet Prize, Tokyo

Dr. Eugen Seibold, professor emeritus at the University of Kiel, is a marine geologist whose career has been devoted to exploring seafloors and the processes that shape them. Through his important seminal research ranging from coastal waters to deep-sea zones, Dr. Seibold has informed and inspired a generation of marine geology researchers.

Conducting his research from a geological perspective, Dr. Seibold has promoted an integrated, interdisciplinary approach to marine geology by combining geophysics, geochemistry, oceanography, marine biology, soil engineering, and environmental science, and his research has covered a broad range of activities. Lauded as a researcher of extreme foresight, Dr. Seibold has accumulated experience and knowledge that bear directly on solutions to global environmental problems.

Dr. Seibold received his Ph.D. from the University of Tübingen in 1948. In 1954, he was appointed associate professor at the University of Tübingen and in 1958 joined the University of Kiel as a full professor and director of the Geological-Paleontological Institute. From 1980 to 1985, Dr. Seibold served as president of the Deutsche Forschungsgemeinschaft and from 1984 to 1990 as president of the European Science Foundation. Since 1986, he has been an honorary professor at the University of Freiburg.

Essay

Earthquakes and Volcanic Eruptions: Protection versus Prediction

Professor Dr. Eugen Seibold

February 1997

We usually regard our Earth as a symbol of solidity. To us, it is the soil on which we stand firmly with our two legs, the bedrock for our buildings and their reliable foundations. But this solid bedrock is only a thin crust about 100 km thick. The material underneath, in the earth's mantle, reacts plastically, like paste. In places where it reaches the surface, as in volcanoes, it may even become fluid and flow out as lava. However, the mantle material as a whole is moving, too, if only by a matter of centimeters a year, dragging the brittle crust above it along with it. Because of its movements in different directions the brittle part, called the lithosphere, breaks into pieces of various dimensions.

The biggest of these, the so-called plates, may move apart, as often happens underneath the central parts of our oceans. At what is known as their divergent plate boundaries, this results in provinces of active volcanism and minor earthquakes, for example in Iceland. If the plates pass each other in a strike-slip fashion, earthquakes may occur, as around the San Andreas Fault in California. In the convergent plate boundary regions, one plate normally plunges underneath its neighboring plate and finally reaches the earth's mantle, where it is incorporated again. Many active volcanoes and some major earthquakes occur around these "subduction zones." The Pacific, for example, is surrounded by convergent plate boundaries which form a volcanic "ring of fire."

For three decades, the theory of plate tectonics has enabled us to explain the origin and distribution of many volcanic eruptions and earthquakes. It has also provided initial data which can provide regional warnings of such natural disasters.

Projections suggest a global population of more than 10 billion for the beginning of the next century. From a regional point of view, this number is even more dramatic than when seen in the global context because humans tend to concentrate in urban agglomerations. Growing cities need more and more underground pipelines for energy, water, and traffic. Therefore they become increasingly vulnerable to earthquakes. In Greek antiquity the City, or Polis, was a symbol of protection against life-threatening situations. Today, things are becoming different. Many of these agglomerations are situated near convergent or strike-slip plate boundaries (Fig. 1) and nearly all major losses of life from earthquakes are concentrated there (Fig. 2).

Risk Maps

Figure 2 presents a kind of risk map. Its large scale is, of course, unsuitable for detailed plan-

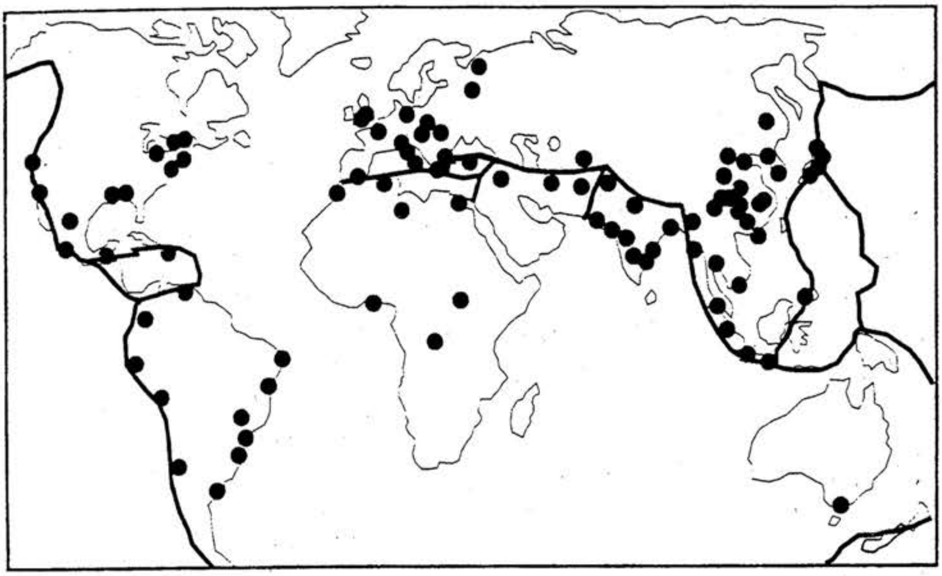


Figure 1 Distribution of cities with a projected population of two million or more in the year 2000. Bold lines represent converging or strike-slip boundaries, explained in the text.

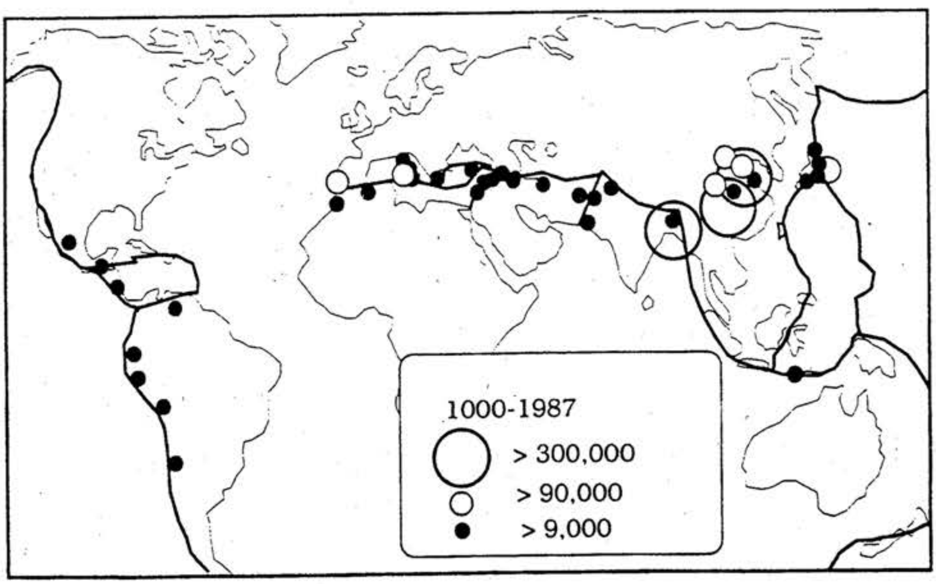


Figure 2 Distribution of earthquakes in the past 1,000 years in which more than 9,000 people died. Most occurrences are located near plate boundaries.
(Figures 1 and 2 after R. Bilham-Cires, *Nature*, Vol. 236, 1988, pp. 625-6.)

ning and practical purposes. To be useful, risk maps must be constructed on a much smaller scale. Factors that are morphological (e.g. slope stability), geological (fault patterns, occurrence of hard rocks or unconsolidated sediments from rivers, the sea or artificial infillings etc.) or oceanographic (exposure of near-shore areas to tsunamis etc.) have to be combined with historical investigations into the locations and magnitude of former earthquakes. The situation in

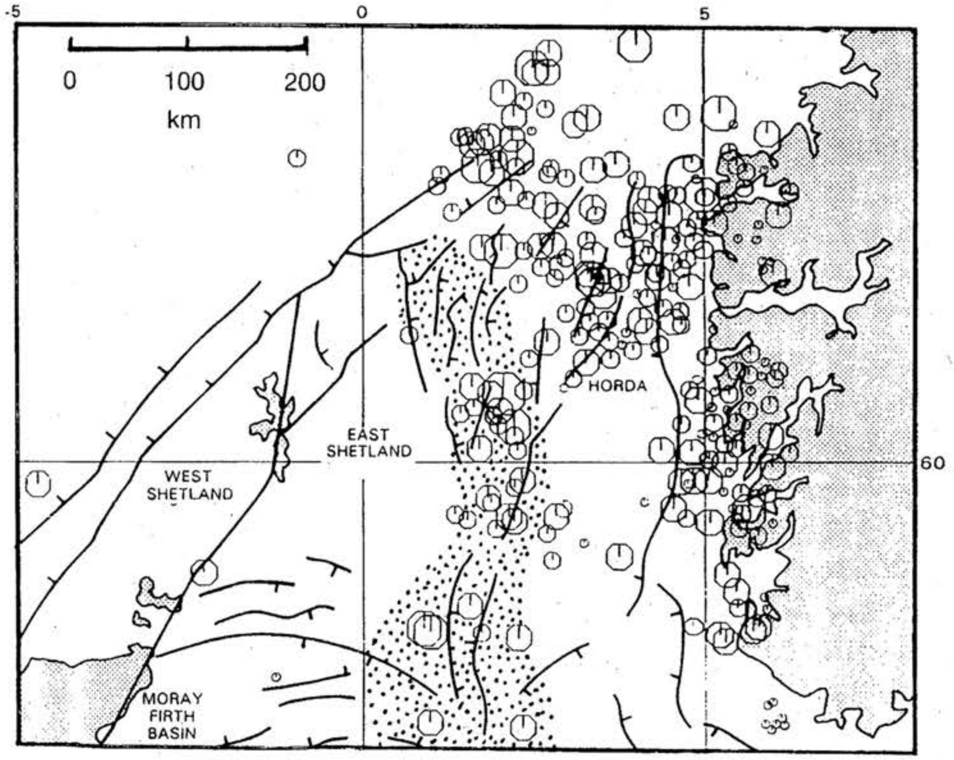


Figure 3 Earthquake risks for offshore structures. Earthquakes between 1980 and 1985 with different magnitudes (circles) are concentrated near the west coast of Norway, especially near faults. The most important offshore platforms for the production of oil are situated in the shaded area.
(After E. Seibold, *Entfesselte Erde*, DVA, Stuttgart, 1995, p. 141.)

parts of the North Sea is illustrated in Fig. 3. Only after such preliminary studies can microzoning risk maps be constructed as a base for land-use planning and detailed advice for sites concerning earthquake-resistant structures.

Similar risk maps should be made for the environment of active volcanoes. Valleys with possible lava or pyroclastic flows are especially dangerous, as was demonstrated during the 1990 Unzen eruption in Kyushu, Japan. Ashfalls are concentrated in leeside areas of prevailing winds. An example is given in Fig. 4.

Prediction of Natural Hazards

There is a curious antagonism in Earth sciences. Thanks to the relatively new theory of plate tectonics we are able to define, on a global scale, the most dangerous regions where major earthquakes and volcanic eruptions may occur, namely near plate boundaries. (Nevertheless, there are exceptions: both the catastrophic earthquake near New Madrid in the U.S. heartland and the Cameroon volcano in Africa both happened within plates. These and similar occurrences cannot be explained simply by plate tectonics.)

In spite of the knowledge of plate tectonics, long-term predictions of earthquakes or volcanic eruptions are very difficult. Unfortunately, it still remains one of our biggest challenges to

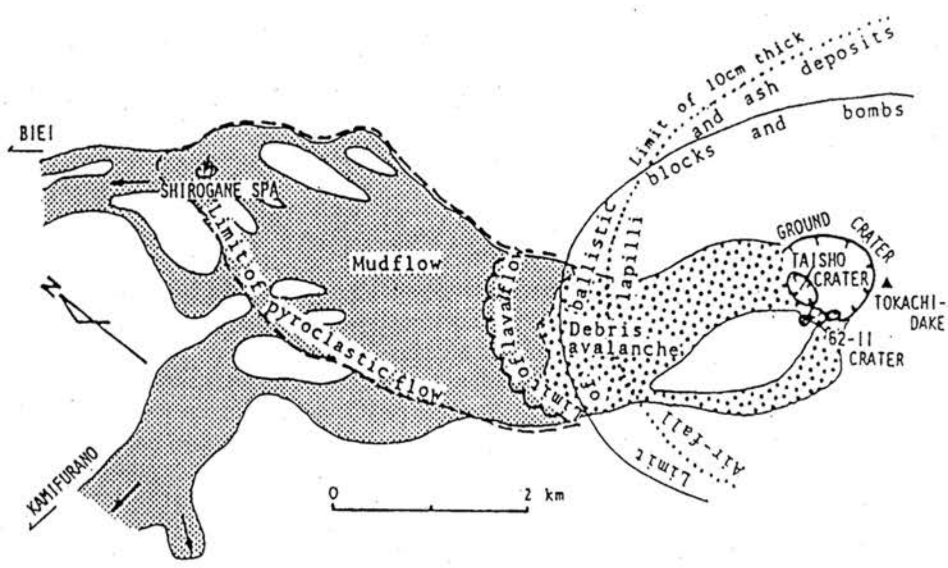


Figure 4 Risk map of Tokachi Dake volcano (Hokkaido, Japan). Mud flows (shaded areas) are threatening wide areas. Limits of possible pyroclastic and lava flows are indicated. Prevailing westerly winds transport blocks, bombs, and ashes mostly to the east.
(Made available by Yoshio Katsuo, Sapporo, 1992.)

forecast such events precisely—where, when, and with what magnitude an earthquake or eruption will take place. Some pessimists even believe that such forecasts will be possible only in exceptional cases. It is easier to forecast volcanic activity because in this case we can concentrate our efforts on one spot, the volcano itself. Continuous monitoring in the field from observatories or even from satellites with thermosensors helps, and such volcanoes as Vesuvius, Etna, Kilauea, or Mount St. Helen are excellent examples of successful predictions and even short-term forecasts.

Forecasting, if it is carried out well, is part of human self-protection. This was excellently demonstrated during the sudden 1991 eruption of Mount Pinatubo in Luzon, the Philippines. The volcano had been dormant for six centuries. However, careful observations, together with a well-organized alert system, mitigated loss of life dramatically.

Wrong forecasting results in public disappointment and fuels the criticism of science in general, as was illustrated by the forecast of an eruption of the Souffrière volcano in Gaudeloupe in 1976. Fortunately, the eruption did not occur—although 72,000 people were evacuated in vain for several months. On the other hand, Colombian authorities failed totally on the occasion of the catastrophe caused by the eruption of Nevada del Ruz, the most northerly volcano of the Andes. They did not react properly to the justified warnings issued before the eruption in 1985—and 25,000 people were killed. Even so, scientists cannot always decide which volcanoes-active or dormant—are more dangerous, or whether active faults are more conducive to earthquakes than dormant ones.

Predictions or even forecasts of earthquakes are much more difficult than for volcanic eruptions. Earthquakes may occur anywhere in fault zones hundreds or even thousands of kilometers in length. Up to now, all our efforts have had no convincing results except in some lucky instances. The usefulness as warnings of small precursor quakes or the often observed pseudocyclicity of earthquakes at a given location have not proven to be reliable. The same is true of the use of geodetic as well as several geophysical and geochemical methods and of the observation of unusual behavior in animals.

Why have the results of very intensive research all over the world to improve earthquake predictions been so disappointing up to now? The material and structural conditions including the influence of fluids underground are different regionally. In addition, these extremely complex systems are chaotic and imply all sorts of nonlinear difficulties. What is worse, there are still many fundamental gaps in our understanding of basic principles and processes. In what way and how strongly do stresses accumulate in the earth's crust? How do fractures form and expand? Which messages from the earth's mantle underneath a volcano are reliable? How do they come to the surface? Why are there fewer dangerous explosions with ash falls, but, on the other hand, more with catastrophic pyroclastic flows?

Prevention

Even if science becomes much more successful in predicting natural disasters, people, organizations, and public authorities must be better prepared to face them. Nature produces earthquakes and volcanic eruptions and we can do nothing but react. We have to obey nature's laws when planning suitable manmade structures and we must try to avoid settling in high-risk areas in spite of growing populations. As in medicine, prevention is better than cure. Therefore, the siting of nuclear power plants, chemical factories, roads, schools and all other forms of concentrations have to be planned carefully on the basis of risk maps. Geotechnical engineers have to improve hazard-resistant designs, following official building codes that must undergo continuous improvement.

Of course, there are many other factors that surpass the competence of scientists or engineers, as in the improvement of public education and plans to prepare for medical and technical emergencies, in the adaptation of legislation to such hazards or in the contrivance of suitable financial measures such as insurance schemes.

Increasing population density increases not only risks in general, but also those specific risks for scientists involved in studying this problem. In medieval times in Europe, natural hazards were treated as God's punishment. Since the Enlightenment, God has been replaced by Fate. With growing scientific success in some of the fields discussed, things look less inescapable. Therefore scientists will increasingly be blamed if they are unable to give at least an earlier or a more exact warning before a disaster. Thus, we have to continue basic research in order to arrive at a better understanding of the mechanism of earthquakes and volcanic eruptions. With this better knowledge we can hope to improve ideas and methods for better predictions. However, at present, it seems to me that multidisciplinary approaches to the improvement of all sorts of prevention are even more important.

Lecture

The Seafloor as Part of Our Environment

Professor Dr. Eugen Seibold

To the audience of a Blue Planet Prize lecture, it is well known that our Earth is the only planet with fluid water and that this is the precondition for both our oceans and for life. Of course, it is also known that the oceans cover more than two-thirds of our globe, of our blue planet.

This means that there are many interactions between sea and land environments. Through evaporation, the oceans supply the remaining third of our globe, the land masses, with rain and snow. With their currents, they transport heat from the equator to polar regions and influence the wind system. The oceans are therefore a weather machine controlling continental droughts or river floods, together with agriculture or traffic. In this way, they even influence our daily life. Long-term variations in this dynamic system determine climatic fluctuations with drastic consequences for our environment.

Oceans are as deep as our highest mountains are high. Ocean dimensions, including their water masses, are huge. They correspond to 160 times the water and ice on land and to 100,000 times the water in the atmosphere. Therefore, the oceans are buffers for all sorts of variations. They may store or release heat or carbon dioxide (CO_2).

Most of these factors that characterize oceanic research require much comprehension on the part of the general public up to the level of governments, and because humankind has begun to influence some of these factors a number of relevant issues concerning the oceans were defined in 1992 in Rio in a 540-page document, Agenda 21. This came as a result of the United Nations Conference on Environment and Development (UNCED).

The Third Blue Planet Prize Academic Award is given to a marine geologist, and I can only accept this honor if I see myself as a representative of my many colleagues around the world. What is a marine geologist? A marine geologist investigates the present situation of the seafloor and the processes which shape it. Furthermore, he tries to learn from the layers beneath the seafloor, i.e., he tries to learn from the past. With this knowledge from the present and the past, he has a responsibility to comment also on future developments if he is able to do so with scientific reasoning, and I would like to stress this aspect.

With the following remarks, I shall try to illustrate some of these points with a few examples from my own work during the last decades. I would like to invite you to come with me to the coasts, where I shall stress coastal management, then to the shallow seas with some remarks about pollution, then to the continental margins with their potential petroleum resources, and finally to the deep sea with its sediments as archives for historical climatic changes. Let us go to the coasts.

Coasts

For two decades after the end of World War II, we had no oceangoing research vessel in

Germany. Therefore, we concentrated our efforts on the North Sea and Baltic Sea and their coastal regions. In any case, the marine environment begins at the coasts and with its many interactions with the neighboring inland. It is said that 80% of the world's population is settled in the 50-kilometer zone along the shores.

The coasts are very peculiar landscapes because they are shaped by processes belonging equally to the hydrosphere, the atmosphere, and the lithosphere. Water, air, and rocks must therefore be studied.

Waves and currents may be destructive and cause coastal erosion. They can also be constructive in transporting sand and forming offshore bars, as in the Baltic. Of course, harbor authorities have to fight against this type of sand transport. For them, sand and mud coming from offshore or from rivers is a kind of pollution.

To obtain qualitative or even quantitative data, one uses tracer sands and one has to observe the sea bottom carefully for bed forms indicating currents, especially with the help of enthusiastic divers, ideally students. Furthermore, one has to combine all these measurements and observations with hydrodynamic calculations and models. These and other coastal problems are an immense task even for a country like Germany, which has only a few centimeters of coastline per inhabitant. Japan, with its 3,600 islands and a coastline of about 27,000 kilometers, has about 23 centimeters of coastline per inhabitant and therefore has much more to do with coastal management than we do in Germany.

Everyone who is concerned with such questions will know that coastal management is even more important for developing countries. In fact, in such regions, it is probably the most important oceanic aspect. How should the coast be developed? Should one dig out channels for bigger ships and harbors? Establish water-dependent industries, like nuclear reactors? Protect lagoons for breeding marine animals? Or protect sandy beaches for tourism? Use beach and dune sands as mineral resources? In many cases, one special use excludes others. Therefore, the marine geologist has to give advice in examining the consequences of different potential uses. But before that he must try to understand the processes behind the screen.

I would like to give only one example, from the coast of India. Tropical weathering conditions destroy quartz and other minerals more than some so-called heavy minerals and ore particles containing iron, titanium, gold, platinum, thorium, zirconium, and so on. Near-shore processes can concentrate them to so-called placer deposits. India is famous for such beach placers around the semicontinent.

How do placers originate? I cannot go into detail, but the processes involved have much in common with panning for gold, as we could demonstrate in beach studies. Of course, this is a problem for fundamental research, but its investigation helps toward exploring placers if you apply this principle to beaches where monsoon waves attack dune sands, like in India. The combination of both is the optimum for placer exploration.

A geologist always has in mind that the sea level has risen by some 100 meters since the melting of the huge continental ice masses some 15,000 years ago. Therefore, former beach sand placers can be expected offshore. Of course, all other mineral resources, including oil and gas, are also products of concentration by nature to be studied by geologists.

We know as well that at present the sea level is rising in most regions by some millimeters per year—here in Japan, too—and that this rise can be accelerated by further global warming, a dramatic threat for lowlands and many islands. But it would lead us too far to treat these aspects today. Now let us go to the second chapter, the shelf seas.

Shelf seas

Offshore we enter the so-called shelf sea with water depths up to about 200 meters. Here we need well-equipped ships and special instruments to study morphological features of the seafloor or to recover sediments and organic remains from the surface or from cores in the sediments. For example, underwater side-scan echo sounders reveal details down to the centimeter, such as ripple marks and other current indicators, where you have an indication that the bottom current is flowing this way or that way, or not at all. In order to obtain large-volume sediment cores for the distribution of samples to all interested specialists, at the University of Kiel we developed the box corer. It was emphasized yesterday that one of my specialties was to always stress interdisciplinary approaches for solutions to problems. Interdisciplinary means that one needs a lot of material, and therefore we developed this special sampler, the box corer.

Trying to approach environmental problems, I concentrated for years on the comparison between the Baltic Sea and the Persian (Arabian) Gulf. Both are adjacent seas to the great oceans and are enclosed by land masses. Therefore, land climate dictates many processes in these marine environments.

The seas in the arid climatic belt, characterized by excess evaporation, have a common and typical exchange pattern with the open ocean: shallow water flows in and deep water flows out. Typical examples are not only the Gulf, but also the Mediterranean Sea and the Red Sea.

Here the loss of water by evaporation greatly exceeds the influx from rain and rivers. Thus, the sea level drops and water enters from the open ocean at the surface to replace the losses in the basin. Evaporation in the basin increases the salinity, and therefore the density of the water, which makes it sink. This sinking is a motor for outgoing currents of heavier deep water, flushing out many kinds of pollution.

The reverse situation can be studied in the Baltic, Black Sea, and in northern fjords: shallow water flows out and deep water flows in, because here rain and river influx exceed evaporation.

One of the consequences of the influx of heavier, saltier bottom water to the Baltic is a relatively stable stratification of the adjacent sea water column, preventing oxygen from the air reaching the deeper parts where hydrogen sulfide (H_2S), a poisonous gas, can develop and kill everything. Pollution by sewage discharge from about 20 million people and industrial wastes, together with fertilizers from agriculture, increase organic productivity and therefore deep-water oxygen deficiency—a continuous threat to surface waters and the organisms in them, because H_2S can reach the surface when there are storms.

I would like to bring just one example from our fieldwork to your attention. These are investigations in the channels of the North Sea going to the western part of the Baltic. Here, we were able to investigate the sea bottom to discover current indicators. These current indicators show both the bottom-water influx and the outflow of surface water in shallow areas. Now let us go to the continental margins.

Continental margins

The continental margin begins with the shelf. We continue on, crossing the continental slope and descend to water depths of about 4,000 meters, where the deep sea, strictly speaking, begins. I would like to stress only one aspect, the opportunities for finding offshore oil and gas underneath our continental margins.

Continental margins are the dumping sites for the debris coming from the continents. Therefore, they may collect sediments of thicknesses surpassing 10 kilometers. Furthermore, these sediments contain a high proportion of organic matter because of the high productivity of the oceanic regions around the continents. Both facts favor the formation of oil and natural gas. This formation and the migration to reservoir rocks require higher temperatures underground and some time in geological dimensions. A sediment cover of one to two kilometers is generally necessary for these processes to happen. As the sediment cover of vast parts of the deep sea is too thin and also too young, more than 80%—and that is a very important figure—of the oceanic seafloor offers no chance for exploration of oil. This very disappointing figure of 80% is deducible from the concept of plate tectonics, a rather new concept of how the ocean and the ocean crust are formed which I cannot treat here today. This is one of the exciting consequences of the application of an academic hypothesis, and it clarifies important aspects of global energy resources.

Plate tectonics also sheds light on the character of Japan's continental margin, the nature of which causes many problems. It is a so-called active margin shaping your environment in many respects. A lithospheric plate sinks beneath another one, accompanied by earthquakes, volcanic eruptions, and extreme disturbances of the sediments there. This plate is sinking down underneath Japan, and in this region earthquakes occur, and when going deeper everything is melting, and you get the Fujis here on your islands. The Japan Sea is a very complicated area upon which I will not touch too much now.

Now why is it so disappointing for oil companies? First of all, all these movements below are very complicated and create complicated structures, as we could see in the Nankai Trough of Japan between Shikoku and Honshu in a 1990 drilling expedition on the vessel *Joides Resolution*. In addition to that, unfortunately, potential sandy reservoir rocks here are mostly cemented and offer insufficient permeability for oil. This is because these sands are of volcanic origin and therefore chemically very reactive. There are a lot of negative points for oil exploration around Japan.

In 1975, I worked as co-chief scientist aboard the drill ship *Glomar Challenger* off West Africa, a typically passive continental margin. In all types of passive continental margin, thick sediments, a succession of possible source and reservoir rocks like porous sandstones or cavernous limestones, and many other positive features come together. However, I would prefer not to go into more detail, but rather to add some general remarks.

At present, world production of oil is about 3.15 billion tons annually. Around 30% comes from offshore. A total for potential global resources, as well as reserves, is hard to estimate. World resources may reach 200 to 300 billion tons of oil. As opposed to this, world reserves of producible petroleum under the prevailing economic and technological conditions are estimated to reach only about 135 billion tons.

As a geologist, I am not stressing the so-called static life expectancy of the oil reserves; at present, they are good for only some 43 years, given the proven reserves divided by annual production. But of course, geologists and geophysicists are talented and will find new reserves, and therefore it will last longer. As a geologist interested in much longer time spans, I can calculate that nature needed millions of years to accumulate these resources.

By an order of magnitude, nature over a period of time collected only some 2,000 tons of oil annually: if you divide 300 billion tons, for example, by 150 million years, you get the incredibly low figure of an annual natural production of 2,000 tons. And we use three billion tons a year. Therefore, this ratio is very bad—about 1:1,500,000 or 1:2,000,000. We are thus guilty of incredible exploitation, even robbery, without an eye to future generations.

Even more generally speaking, for me the energy supply for both the industrialized and developing countries should be top priorities on our problem-solving global agenda. Because with energy you can even convert sea water into fresh water for irrigation. It is nonsense, of course, because it is too costly and not energy-efficient, but in principle you can do it. Now let us go to the deep sea.

Deep sea

I would like to demonstrate that deep-sea sediments are excellent archives for environmental changes, and with modern methods we can even make up for some losses or disturbances of the archive pages. Here, I concentrate on only one aspect, on rhythmicity in many sequences of deep-sea sediments, as in deep-sea drilling cores off West Africa. This alternation is a sequence between whitish layers, i.e., layers rich in calcareous particles, and darker ones called marls with higher quartz and clay mineral contents.

How can we explain these sequences? There are many possibilities. In a detailed analysis, we were able to prove that here the most important factor was different dissolution of calcareous particles and, additionally, that the periodicity of the fluctuations was around 40,000 years. This was the situation in the Atlantic some 15 million years ago. Fluctuation at that time was mainly controlled by processes in high latitudes, around Antarctica and in the northernmost Atlantic and in the Arctic Ocean.

Climatically, the Atlantic is the most sensitive ocean because it is connected with both polar seas. The Pacific, on the other hand, is separated from the north by the Bering Strait, which is too shallow for deep-water exchanges.

However, much more sophisticated methods used during the last few decades disclosed truly revolutionary relations between deep-sea sediments and climatic oscillations. One uses tiny organisms like foraminifera whose tests consist of calcium carbonate, $CaCO_3$. They contain oxygen which is taken from sea-water. The ratio of oxygen-16 to oxygen-18 indicates mainly the volume of ice masses stored at any given time, i.e., in colder or warmer phases, on the continents during the last two to three million years, the so-called ice age.

From a deep-sea sediment core, which is over 10 meters long, one can give a summarized survey of the last 400,000 years. I included an example in a textbook translated into Japanese eight years ago because it looks to me like a musical score with its rhythmic and melodic variations. One can easily see prominent 100,000-year cycles for this period. In the curves, downs are colder phases called glacials, and ups are warmer phases called interglacials. Additionally, downs mean lower sea level because of the ice masses stored on the continents. Fortunately, at present we live in an interglacial. Seen geologically, it looks reasonable to say that in some millennia we shall approach a new glacial phase.

The summary curves also reveal smaller ups and downs. But let us stress only one of the many aspects being discussed at present for possible future climatic fluctuations: How quickly can these fluctuations occur?

In a sediment core from the Atlantic off West Africa, in about a 5.5-meter core depth we found a boundary between greenish and greyish colors. It marks the beginning of the last interglacial, some 140,000 years ago. The boundary is very sharp. Therefore, the transition probably took only some centuries to happen. The core was taken on *Meteor Cruise 25* in 1971. Since then I have emphasized how rapid such transitions of our climatic system can be because the system is nonlinear. We should bear in mind that such rapid changes could occur in the future, too, if we approach a threshold for one or several factors. An increase of global temperatures or growing CO_2 contents may be examples of such factors causing climatic change.

Indeed, many more and partly extremely rapid variations were recently discovered in two Greenland ice cores. According to these results, our colleagues believe that temperature changes of several degrees centigrade may occur even within a few decades. But as yet most of these minor variations have not been discovered in the Russian Antarctic ice core Vostok. Hopefully, the planned Japanese Antarctic ice-core drilling can add much new information.

But we have to keep in mind that these changes I have been pointing out in these ice cores are atmospheric changes. We have to deal with changes of the oceanic system, with huge water masses which store such huge amounts of heat and which buffer all sorts of variations. Thousands of years may elapse before relevant climatic changes are to be felt in the oceans globally. This is reassuring for us on one hand, but alarming on the other. Devastation on land with landslides, soil erosion, or river pollution is directly visible. In our oceans, long-term variations prevail and countermeasures may therefore come too late.

Conclusions

But now back to marine geology, back to going aboard, and back to the many different feelings evoked by the vast oceans. Of course, cool, sober, objective oceanography and marine geology are only one part of the approach to the seven seas and to our blue planet. We cannot leave out emotion. Thomas Mann once observed that "the sea is not landscape; it is expression of eternity, of nothingness and death, a metaphysical dream." According to Paul Valery, "a look at the sea is a look at the possible."

I identify more closely with Valery's vision. Also, I appreciate the atmosphere aboard a research vessel, as did Henry Stommel of Woods Hole in the United States, the pioneer of Gulf Stream research, who wrote that "work at sea rubs off the sharp edges and makes us better people. The ship becomes a home away from home." This statement implies many facets even of the ocean itself. The ocean is a good teacher which deals with many different people, with many disciplines, and with problems in space and time of very different dimensions. We have to measure ocean currents in meters per second, but the growth of deep-sea manganese nodules in millimeters per million years.

As a university professor I am a teacher, too. Therefore, I am grateful for a generally friendly "teacher ocean" and for the fact that it can be mastered by many excellent ship crews. I am grateful to all my exemplary teachers in science and to all friends and colleagues around the globe, including those in Japan, who are giving me advice. But a good professor should only be happy if he has students and collaborators who will surpass him in research. Looking around in Germany and abroad I feel really happy that many of my former students are surpassing me in research. I am especially grateful to them as well.

Finally, I would like to give thanks to the people at home, away from my home at sea, and first of all to my family.

In summary, I have tried to demonstrate some relationships between the seafloor and the environment from the coast to the deep sea and from the present to the past and possibly to the future. But I had to select only very few mosaic stones from my own work and the work of the Kiel team. These stones must represent reliable results. Only then can you use these stones to put together at least the design of the whole mosaic. I suppose that the Blue Planet Prize was given to me because I have always stressed the importance of careful and reliable investigations as a base for more general statements.

Of course, we all have to think globally, but just like in daily life we have to begin with regional or even with local actions and investigations. The ocean, however, where everything reacts with everything and where there are no real boundaries, offers better opportunities to think globally than do the continents. What a challenge to unveil the secrets of the sea and what a chance to use some of the results and apply them to urgent problems of present and even future global, regional, and local environments. Thank you very much.

Major Publications
Professor Dr. Eugen Seibold

Books

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Profile

Lester R. Brown

Founder and president of the Worldwatch Institute

Education and Professional Activities

1955	B.A., Rutgers University
1959	M.S., University of Maryland
1959–69	U.S. Department of Agriculture
1962	Master of Public Administration, Harvard University
1969–74	Senior Fellow, Overseas Development Council
1974–	Founded the Worldwatch Institute, serving as its president through the present

As founder and president of the Worldwatch Institute, Lester R. Brown is responsible for one of the world's leading private-sector think tanks focusing on global environmental problems. Conducting some of the world's most innovative, relevant global environmental research, the Institute has sounded the alarm on numerous environmental issues.

The Worldwatch Institute analyzes global environmental problems and proposes solutions, publishing its findings in a variety of reports. For example, in 1984 the Institute launched its annual *State of the World* reports, which provide an insightful assessment of the world's resources and how they are managed. Influencing politicians and corporate leaders worldwide, these publications have offered statistical and theoretical support to the global environmental movement.

Mr. Brown received his undergraduate degree in agricultural science from Rutgers University in 1955, after which he spent six months in India with the International Farm Youth Exchange Programme. In 1959, he received an M.S. degree in agricultural economics from the University of Maryland and entered the U.S. Department of Agriculture's Foreign Agricultural Service. In 1969, he left government to help establish the Overseas Development Council, where he remains a senior fellow. In 1974, Mr. Brown founded the Worldwatch Institute.

The Acceleration of History*

Lester R. Brown

The pace of change in our world is speeding up, accelerating to the point where it threatens to overwhelm the management capacity of political leaders. This acceleration of history comes not only from advancing technology, but also from unprecedented world population growth, even faster economic growth and the increasingly frequent collisions between expanding human demands and the limits of the earth's natural systems.

History is not about the status quo; it is about change. Throughout most of the time since civilization began, the agents of change worked slowly. Until recently, in historical terms, the growth of population was so slow as to be imperceptible during an individual's lifetime. Economic expansion was similarly sluggish. But since mid-century, the pace of change has been breathtaking.

Today, it is difficult to grasp the sheer magnitude of human population growth. Those of us born before 1950 have seen more population growth during our lifetimes than occurred during the preceding four million years since our ancestors stood upright.

As population has doubled since mid-century and the global economy has nearly quintupled in size, the demand for natural resources has grown at a phenomenal rate. Since 1950, the need for grain has nearly tripled. Consumption of seafood has increased more than four times. Water use has tripled. Demand for the principal rangeland products, beef and mutton, has also tripled since 1950. Firewood demand has tripled, that for lumber has more than doubled and for paper has gone up by a factor of six. The burning of fossil fuels has increased nearly fourfold and carbon emissions have risen accordingly.

These spiraling human demands for resources are beginning to outgrow the capacity of the earth's natural systems. As this happens, the global economy is damaging the foundation upon which it rests. Evidence of damage to the earth's ecological infrastructure takes the form of collapsing fisheries, falling water tables, shrinking forests, eroding soils, dying lakes, crop-withering heat waves and disappearing species.

Even as the effects of unprecedented population growth are threatening to overwhelm some governments, the collision between the expanding demands of the global economy and the earth's natural limits are creating additional burdens. Collisions with the sustainable yield limits of fisheries, aquifers, forests, rangelands, and other natural systems are occurring with increasing frequency. As a result, national political leaders and the UN agencies are spending more and more time dealing with these collisions and their consequences: fishery conflicts, water scarcity, food shortages, increasingly destructive storms and swelling flows of environmental refugees.

* Excerpted from Lester R. Brown, "The Acceleration of History," in *State of the World 1996*, W. W. Norton & Co., New York.

As the change in the relationship between our growing numbers and the natural systems on which we depend accelerates the pace of history, the realization that we may be facing a shortage of food from both oceanic and land-based sources is a troubling one. Thoughtful people reflecting on these trends are asking, Can we avoid catastrophe? The answer is yes, but not if we keep sleepwalking through history.

Avoiding catastrophe is going to take a far greater effort than is now being contemplated by the world's political leaders. We know what needs to be done, but politically we are unable to do it because of inertia and the investment of powerful interests in the status quo. Securing food supplies for the next generation depends on an all-out effort to stabilize population and climate, but we resist changing our reproductive behavior and we refrain from converting our climate-destabilizing, fossil-fuel-based economy to a solar/hydrogen-based one.

As we move to the end of the century and beyond, food security may well come to dominate international affairs, national economic policymaking and, for much of humanity, personal concerns about survival. There is now evidence from enough countries that the old form of substituting fertilizer for land is no longer working that we need to search urgently for alternative formulas for humanely balancing our numbers with available food supplies.

One of the most obvious needs today is for a set of country-by-country carrying capacity assessments. Assessments using an interdisciplinary team can help provide the information needed to face the new realities and formulate policies to respond to them.

The growing gap between food demand and food supplies at familiar prices underscores the need for governments to assess their national carrying capacities so that they and the people they serve can understand the difficult choices that lie ahead. Now that the global fish catch has leveled off, we have a good sense of just how much food the oceans can provide sustainably. We now know roughly both how much land will be available for food production in the future and, based on yields achieved by the most agriculturally advanced countries, what the yield potential of that land is with existing technologies. Barring any new technologies that can lead to quantum jumps in food production, like the discovery of fertilizer or the hybridization of corn, the world is facing unprecedented difficulty on the food front.

On the demand side of the food-population equation, the information needed to calculate future carrying capacity for varying combinations of projected population size and consumption levels is now available. These carrying capacity assessments can help people understand more clearly the difficult choices to be made between family size today and food consumption levels tomorrow. They will help everyone better understand the trade-off between the reproductive rights of the current generation and the survival rights of the next.

The lack of growth of the world grain harvest since 1990 coupled with the continuing growth in world population and the increased likelihood of crop-damaging heat waves in the years ahead at least carries the potential of severe food shortages. The economic disruption that is likely to result could dwarf that when the Organization of Petroleum-Exporting Countries engineered a tripling in the world price of oil in 1973. People can survive without oil, but not without food. Oil can be replaced with other energy sources, but there is no replacement for food.

No other economic indicator is more politically sensitive than rising food prices. If the grain shortage that will now continue at least until the 1996 harvest begins should continue indefinitely, millions of low-income breadwinners could face food price rises that would threaten the survival of their families. Food prices spiraling out of control could trigger not only economic instability but also widespread political upheavals. Food scarcity could call into question the legitimacy of numerous national governments that have failed to address the growing imbalance between human reproduction and food production.

The world today is faced with an enormous need for change in a period of time that is all too short. Human behavior and values, and the national priorities that reflect them, change in response to either new information or new experiences. When Nobel laureates Sherwood Rowland and Mario Molina published their landmark article in 1974 outlining the threat to the stratospheric ozone layer from CFCs, they convinced many thoughtful people of the need to phase out the use of these chemicals. But it was not until two British scientists discovered the "hole" in the ozone layer over Antarctica that the international movement to ban CFCs gained enough strength to succeed.

The questions now are, What will be the climate equivalent of the hole in the ozone layer? What will trigger a meaningful response? Will it be crop-withering heat waves so intense that they create food shortfalls so massive that the resulting food price rises destabilize the world economy? What will finally convince governments that unless population is stabilized sooner rather than later, falling food consumption per person will spread, engulfing an even larger share of humanity?

The effort now needed to reverse the environmental degradation of the planet and ensure a sustainable future for the next generation will require mobilization on a scale comparable to World War II. As noted earlier, regaining control of our destiny depends on stabilizing population as well as climate. These are both key to the achievement of a wide array of social goals ranging from the restoration of a rise in food consumption per person to protection of the diversity of plant and animal species. And neither will be easy. The first depends on a revolution in human reproductive behavior; the second, on a restructuring of the global energy system.

Serving as a catalyst for these gargantuan efforts is the knowledge that if we fail, our future will spiral out of control as the acceleration of history overwhelms political institutions. It will almost guarantee a future of starvation, economic insecurity, and political instability. It will bring political conflict between societies and among ethnic and religious groups within societies. As these forces are unleashed, they will leave social disintegration in their wake.

Effectively dealing with many of the issues now confronting humanity requires a strong set of global institutions. In today's world, for example, with modern transportation and the continuous flow of people and other disease vectors across national boundaries, societies are faced with entirely new diseases, ones to which people have little resistance and about which the medical community knows too little. Among these new maladies are Lyme disease, which was first identified in the mid-1970s in Connecticut and has now spread throughout the continental United States and into Western Europe; the AIDS virus, which is now found worldwide though it was unknown to the medical community just 15 years ago; and the Ebola virus found in Zaire.

Disposing of toxic waste, protecting biological diversity and managing oceanic fisheries beyond the national 200-mile limits are but a few of the issues that depend on an international approach. Climate stabilization, like protecting the stratospheric ozone layer, cannot be achieved by societies acting unilaterally. Only a cooperative international effort will suffice, as it did on the CFC issue. It was the leadership of the UN Environment Programme that led to the Montreal Protocol and subsequent amendments that successfully reduced the manufacture of the ozone-threatening CFCs.

Satisfying the conditions of sustainability—whether it be reversing the deforestation of the planet, converting a throwaway economy into a reuse/recycle one or stabilizing climate-will require new investment. Probably the single most useful instrument for converting an unsustainable world economy into one that is sustainable is fiscal policy. At present, governments subsidize many of the activities that threaten the sustainability of the economy. They support fishing fleets to the extent of some $54 billion a year, for example, even though existing fishing capacity greatly exceeds the sustainable yield of oceanic fisheries. In Germany, coal production is subsidized even though the country's scientific community has been outspoken in its emphasis on the need to reduce carbon emissions.

Partially replacing income taxes with environmental taxes is desirable for several reasons. One, income taxes discourage work and savings, which are both positive activities that should be encouraged. At the same time, taxing environmentally destructive activities would help steer the global economy in an environmentally sustainable direction. Among the activities to be taxed are the use of pesticides, the generation of toxic wastes, the use of virgin raw materials, the conversion of cropland to nonfarm uses and carbon emissions. The time may have come to limit tax deductions for children to two per couple: it may not make sense to subsidize childbearing beyond replacement level when the most pressing need facing humanity is to stabilize population.

The shift from income to environmental taxes would be revenue-neutral, but the elimination of huge subsidies for the use of fossil fuels or water, or for investment in fishing trawlers, to cite just a few examples, would free up a vast sum of capital that could be used to fill the family planning gap, develop an energy- and land-efficient transportation system, reforest the planet and educate young women in developing countries—a key to accelerating the move to smaller families. In addition to using tax policy to shift private investment to environmentally sustainable activities, once it becomes clear that it is food scarcity rather than military aggression that threatens long-term political stability, public pressure will develop to reorder priorities in the use of public resources as well. Restructuring private investment through fiscal policy shifts and public investment through an ordering of priorities that corresponds with today's needs can easily provide the resources needed to stabilize both population and climate.

The challenge for humanity is a profound one. We have the information, the technology and the knowledge of what needs to be done. The question is, Can we do it? Can a species that is capable of formulating a theory to explain the birth of the universe now implement a strategy to build an environmentally sustainable economic system?

Lecture

Environmental Revolution

Lester R. Brown

As the countries of the world were preparing for the UN Conference on Population and Development in Cairo in the early months of 1994, one of the questions that was asked frequently concerned how many people the Earth can support. What is the Earth's carrying capacity? In order to answer that question, of course one has to consider other questions, because it's not only how many people that matters, but also their standard of living and consumption levels.

There are many ways in which the growth in human population could be constrained. One could be continually worsening pollution, for example, until it reaches the point where it affects the prospects for human survival, where it affects human health very directly. This is already the case, for example, in the former Soviet Union. More than a year ago, the Institute of Medicine at the Russian Academy of Sciences released its first report on the state of the health of the Russian people. That report said that for the first time in modern history, life expectancy in Russia was declining. It said that 11% of the children born in the previous year had birth defects. It said that 55% of school-aged children had special health problems, that is, problems beyond the normal childhood diseases. Professor Vladimir Prokovsky, who was the head of the Institute of Medicine and the senior author of that report, said that even if all pollution stopped immediately in Russia, they would face deteriorating health conditions for at least the next 25 years. He said that 10% of the food supply was chemically contaminated and 50% of the drinking water in Russia was chemically contaminated. He said the industrial progress of the past 30 years has been bought with the health of the Russian people. And he said that they will be paying that cost for at least another generation.

I cite this as an example of one country that has experienced a reversal in its health conditions as a result of pollution, both chemical and radioactive. But as we look at the world, we do not, even in severe conditions such as those in Russia, see pollution emerging as the principal constraint on the number of people that the Earth can support. Could it be water scarcity that will eventually limit the number of people? I suppose given this past summer here in Japan and particularly in Tokyo, when water was being imported by ship from abroad, the idea that water could become a principal constraint on future population growth might be a bit more plausible than it was before this year. But we don't think that water is going to be an immediate constraint on the growth of world population, in part because most of the water we use is used to produce food. Of all the water that we withdraw from underground aquifers and from rivers and other surface sources, two-thirds is used for irrigation. The other one-third is used for residential and industrial purposes, and so on.

We think the principal constraint on the growth of world population is going to be the food supply. Now this is not a novel idea. As you know, Thomas Malthus presented this idea two centuries ago, so I don't take credit for it. But I do want to say that I think we are moving into a period where the idea that food supply will not increase as fast as population is acquiring a reality that it has not had except for brief periods during the two centuries since Malthus wrote his now famous book.

In looking at the food prospect, we see the emergence of three physical constraints on efforts to expand the world food supply: the limits of oceanic fisheries to supply fish; the limited amount of fresh water that is available; and, something that people do not think very much about, the physiological capacity of crop varieties—rice, wheat, and corn—to use fertilizer. This is also a limit, a natural limit.

Let me talk about each of these briefly. With seafood, we have all lived during a period when the world seafood catch has increased enormously. Between 1950 and 1989, the world fish catch increased more than four times, 4.6 times to be exact, going from 22 million tons in 1950 to 100 million tons in 1989. It was a remarkable period. The average person in the world in 1989 consumed 19 kilograms of seafood, compared with nine kilograms per person in 1950. So the average person in the world doubled seafood consumption from 1950 to 1989. And then suddenly we hit the wall, so to speak. And the seafood catch has not increased at all over the last five years; in fact, it has declined slightly from the 100 million tons in 1989 to between 97 and 99 million tons in the years since then. Because the total fish catch is no longer increasing, the per capita seafood catch is declining as a result of population growth.

The marine biologists at the Food and Agricultural Organization in Rome report that all 17 oceanic fisheries are now being fished at or beyond capacity, and that nine are in a state of decline. Some of them, I might add, are actually collapsing. The cod and haddock fishery off the Canadian coast of Newfoundland has literally collapsed. We read a few days ago that the New England fisheries for cod and haddock may also be closed by the U.S. government in an effort to salvage them.

I've just been talking to the vice president of the UN University in his office upstairs about what's happening to the seafood catch. What will the economic consequences be of a declining seafood catch per person as far as we can look into the future? One of the consequences is rising seafood prices. Thirty years ago people who could not afford meat ate seafood. Certainly, that was the case in the United States. That's no longer true. If you go into a fresh seafood shop in Washington, D.C., or New York, you don't see any poor people there. The prices are too high. So we're seeing a change in the price of an important food product that much of humanity depends on. I would point out that the world fish catch, at 100 million tons, is equal to the world's production of beef and poultry combined. Now that will not surprise most of you in Japan because of the extraordinary levels of seafood consumption in this country. But in other parts of the world, the idea that the seafood catch equals the production of beef and poultry does come as something of a surprise.

So we are pushing against the limits of the oceanic fisheries at a time when population is 5.6 billion. But we're adding 90 million a year, which means that each year you and I as average citizens of the planet will have less seafood than we had the year before. What are the consequences of that economically, socially, nutritionally, politically? No one knows, because no one has been analyzing this issue and looking at it with an eye to the future—a big gap in the global research agenda.

We could talk about water. Water is becoming scarce in many parts of the world. In the United States, we see water scarcity throughout the Southwest, in the states of California, Arizona, Nevada, New Mexico, and Colorado. We see water becoming increasingly scarce in the southern Great Plains of the United States, one of the world's major wheat-growing regions. In the southwestern United States, nearly all the water has now been claimed, whether it's water from, say, the Colorado River, or whether it's underground water supplies. Overpumping is now widespread in this region of the country. When the demand for water in cities increases, they can satisfy it only by taking water away from agriculture, by buying the irrigation rights from farmers. Los Angeles, to get the water it needs, must now get it by taking it away from agriculture.

I have family in ranching in northern Colorado, about 70 miles north of Denver and east of Fort Collins, if you know U.S. geography at all. And in that county, a couple of years ago an agent came in and began buying irrigation water rights from farmers and ranchers, and eventually bought the irrigation rights from a few hundred farmers. He was offering a price that no one could resist, but no one knew who he was buying the water for until he had bought all the rights, and then it was revealed that he was buying the water for a small city near Denver called Thornton, Colorado. They planned to build a 60-mile pipeline and take that water to Thornton to satisfy the needs of this growing city toward the end of this century and in the early 21st century.

That example has been repeated over and over again around the world. In Beijing, which is not a small city, the irrigation reservoirs around that city were once used by both farmers and the city. Recently, farmers were banned. They no longer have access to those reservoirs in the agricultural region surrounding Beijing. They must now either go back to dryland farming, or they must drill wells and pursue the falling water table downward.

To finish with the United States, the Department of Agriculture reports that 21% of all irrigated land in the United States is now being watered by drawing down underground water supplies—by overpumping. In the southern Great Plains of the United States, this is the result of relying on a fossil aquifer, an aquifer that was formed a long time ago in geological time, and which is not today being recharged in any significant way. And so as it drops, eventually farmers have to go back to dryland farming.

In China, a substantial share of the irrigated land is being irrigated by drawing down underground water tables, also. Almost all of northern China is now a water-deficit region; that is, it is using more water than nature makes available. And it is a water-deficit region because it is drawing down the underground water table. One of the interesting geological questions is what happens to a region like northern China when you keep depleting the underground water supplies. What happens to the geological structure, what happens to the aquifers, what happens to the recharge potential? It's an area, I think, that has not been researched in much depth, but even one who's not a geologist can imagine that there will be some lasting consequences.

These are some of the questions that we need to be asking and trying to answer as we try to respond to human needs for water that are growing far more than that which would be required to supply the needs of 90 million additional people each year. Because as incomes rise, people consume more water. What happens to the demand for water as 1.2 billion people in China begin to acquire indoor plumbing, showers and bathtubs, flush toilets, and running water in the kitchen? This may be one reason why 300 of the largest cities in China now are facing water scarcity, 100 of them severe water scarcity. And I have to conclude that in most cases, they will satisfy their future water needs, the deficits that are developing, by pulling water away from agriculture. There is no other place from which to obtain it. Before I leave China, one more point. As you probably know, because of an extreme shortage of water in Beijing, questions are being asked as to whether it should be the capital of China permanently, or whether the capital should be moved to the south, where there are at least adequate water supplies. Another alternative is to move water from southern China, which still has a surplus of water, to the Beijing region with a long canal. This would be roughly 900 miles. It would be as though Washington, D.C., decided to get its water from the Mississippi River, 900 miles to the west. This is a major civil engineering project that is in prospect for China to supply the water needs of Beijing and Tientsin.

In India, water tables are now falling in several states because of overpumping. One of the advances associated with the green revolution over the last few decades has been an increase in the double cropping of wheat and rice. Throughout central and northern India, many farmers grow two grain crops a year: they grow winter wheat, and in the summertime they grow rice. Both crops are irrigated because the wheat is grown during the dry season. And they have greatly increased their production. I helped draft 25 years ago the agricultural plan for India, which led to a doubling of its wheat harvest in seven years, a phenomenal advance. Today, India is facing growing water scarcity and the prospect of cutting back on the amount of double cropping of wheat and rice because there is simply not enough water.

So water is emerging as a constraint on food production. I could talk about other parts of the world, but I've chosen to talk about the United States, China, and India because these three countries are the world's three leading food producers; together they produce nearly half the world's grain.

If land is being irrigated by overpumping, by depleting the aquifer, then at some point when the aquifer is finally depleted the amount of irrigation must be reduced. For example, if the rate of irrigation pumping is double the rate of aquifer recharge, then when you finally hit the bottom you have to reduce the amount of pumping by half, and that means a very substantial cutback in food production. So we're facing some real adjustments ahead on the water front.

The third natural constraint that I mentioned, which has not gotten very much attention compared with water, for example, is the physiological limits of crop varieties to benefit from fertilizers. In 1847, a German scientist, Justus von Liebig, discovered that all the nutrients that plants take from the soil could be returned in mineral form. It was a major discovery. If there were a Blue Planet Prize then, Professor Seibold, he probably would have been the winner instead of you! Yes, he agrees. It was an exciting advance in our understanding of plant growth and nutrition and physiology, but we did not really take advantage of that knowledge until nearly a century later. As recently as 1950, the world was using maybe 14 million tons of fertilizers. By 1989, it had reached 140 million tons, a tenfold increase. It was the growing use of fertilizer that was the engine driving the growth in world food output over the last four decades.

It was fertilizer more than anything else that permitted the farmers on the land in 1950 to double their production within a generation. No generation of farmers in history had ever done that before, but the world's farmers as a group between 1950 and 1980 doubled their harvest and they are still increasing it.

Many of the things that we have done to increase food production over the last four decades have really been designed to increase the use of fertilizer. The reason we irrigate is so that we can use more fertilizer and increase yields. The exciting thing about the dwarf wheats and rices—and that breakthrough came in this country a century ago—is that they can use much more fertilizer than the traditional varieties, the traditional tall, thin straw varieties of wheat and rice. One could easily triple the amount of fertilizer effectively used and increase the yield accordingly.

But since 1989, world fertilizer use has actually declined. In part, that's for agronomic reasons, because in many countries using more fertilizer no longer increases production. So production has leveled off. Farmers in the United States in the early '90s are using less fertilizer than they did in the early '80s, because using more fertilizer doesn't have much effect on output. We could double fertilizer use in the United States next year, and you probably could not see it in the production trend. It would be as though you and I decided that instead of eating three meals a day, which most of us do, we would eat six meals a day. It probably would not increase our productivity very much; in fact, it might diminish it somewhat. Plants are living beings, too, and once you reach the limit of what they can do physiologically, then giving them more fertilizer doesn't have much effect. If you and I were getting only one meal a day and we suddenly were given two meals a day, then we would become much more productive. And that's the way it was with crop varieties and fertilizers throughout most of the last four decades. But suddenly we've reached the point where more fertilizer has little use. Fertilizer use in Western Europe, Japan, and the United States today is no more than it was a decade ago; the trend is basically flat. So that engine which has been driving the growth in food production no longer works very well.

If we can't use more fertilizer, if we can't keep greatly increasing fertilizer use to boost food production, where will the gains come from? How will we feed 90 million more people each year? And the answer is, no one knows.

In talking just a bit ago with the vice president of the UN University, we were discussing the environment and the economy, and the environment and food production. I'm not going to spend more than a few minutes discussing this, but I would point out that soil erosion is now a serious threat to the growth in food production in many parts of the world. It is especially a problem in developing countries. One can hike around the highlands of Ethiopia today and see abandoned villages that 10 or 20 years ago were productive. The reason they have been abandoned is because there's not enough topsoil left to support even a subsistence-level agriculture, much less a market surplus-producing agriculture. The same is true in many of the Andean countries of Latin America, for example. It's true for parts of Indonesia. I could go on and on. Soil erosion is slowly undermining the long-term food prospects on probably 30% of the world's cropland.

Another question is global warming. This summer was a very hot summer in Japan that affected rates of water evaporation. But a very hot summer, if it got much hotter, would also affect rice pollination. If temperatures get too high, rice will not pollinate. Neither will corn, for example. In the United States, in the summer of 1988, when we had record heat and drought, our grain harvest in that year dropped below domestic grain consumption for the first time in our history. We didn't think it was possible, at least I did not think it was possible, that the breadbasket of the world would suddenly find itself not producing enough to satisfy even its own needs. Fortunately, at that time we had enormous reserves. We typically produce about 300 million tons of grain, we use 200 million tons domestically, mostly for livestock feeding, and then we export 100 million tons to something like 100 countries around the world, the largest of which is Japan. Now fortunately that year we had enormous reserves, and so in effect we exported those reserves to satisfy export commitments, again including to Japan. But reserves were drawn down, and they have never been rebuilt. If we had another summer like the summer of 1988, then we would not be able to satisfy export commitments, and then suddenly there would be intense competition among importing countries for inadequate exportable supplies of grain. Prices would double or maybe triple almost overnight, creating instability in the world economy.

In looking at the long-term human prospects and in thinking about the various things that can constrain future progress and destabilize the future both economically and politically, I think it's food that we have to worry about. And the question is, what will happen to bring the food issue into sharp focus? I mentioned the possibility of another summer in the United States like the summer of 1988. That's a possibility, and that would be the wake-up call.

Another possibility, and I think of this as more of a reality, is China's emergence as a massive food importer. We have in East Asia a situation that is unique in that we have countries that are already densely populated before serious industrialization begins. Japan is such a country. When Japan's rapid industrialization and movement toward a modern consumer economy began in the 1950s and accelerated in the '60s and '70s, we had a country where a lot of cropland was used for industrialization purposes. So much agricultural land was lost to non-farm uses—building factories, warehouses, highways, etc.—that grain production actually declined in absolute terms. Grain production this year, which is a good harvest year, as you know, is probably close to 40% less than it was in 1960, or at least something on that order of magnitude. And this is simply because the amount of land loss has outstripped the increase in land productivity. A similar situation exists in South Korea and in Taiwan for the same reasons. The process started there maybe 10 or 15 years after it did in Japan.

As we look at China, we see exactly the same situation: a country that is already densely populated before it moves into the era of rapid industrialization and the establishment of a modern consumer economy. And so what we're looking at in China is the prospect of very substantial losses of cropland over the next few decades, losses so large that they will override the rise in land productivity, leading to an absolute decline in grain production, as has happened in Japan, South Korea, and Taiwan. Japan last year imported 73% of its total grain supplies; although it was almost self-sufficient in rice, it imported all feed grains for livestock and most of the wheat consumed.

It is one thing when a country of 120 million imports 77% of its grain. It is another thing when a country of 1.2 billion people begins moving in the same direction, and that's what we're faced with in China. Unfortunately, most of the analysts of world agricultural supply and demand trends have overlooked this point. They have assumed that China's food production will keep increasing steadily as far as we can see into the future. I don't think that is at all likely. By an accident of history, China is beginning to expand its demand for food at a phenomenal rate at a time when the world is beginning to press against some of the natural limits to the growth in food production. I mentioned the seafood catch, for example. In an earlier period when population pressure built on the land in Japan, you turned to the oceans for your animal protein on a large scale, and this was very successful. The fish and rice diet of Japan began to evolve. That option doesn't exist for China, of course.

So we have the constraint on seafood supplies, we have the constraint on water supplies, and we have the limits on the amount of fertilizer that available crop varieties can use. So we have some constraints emerging just at the time when China is getting ready to move into the world market to import massive amounts of grain. Exactly when that will come we don't know. It could be before the next harvest, because as you may know grain prices in the 35 largest cities in China in August of this year were up 60.2% from August of last year. And this was during the harvest period. We don't know what will happen in the winter months as we look ahead to next year's harvest. We also know that the government in Beijing canceled trading in rice futures on the Shanghai Commodity Market a week ago Friday because they thought there was too much speculation in the market. But it's another manifestation of the degree of scarcity that exists in China.

We know that population growth in China will increase the demand for food, even though it's increasing very slowly by international standards, certainly by Third World standards—a bit over 1% a year. But with such a large population base, this still means China will add 490 million people between 1990 and 2030. That's the population of the United States and two Japans plus. But in addition to population growth, the more important source of growth in demand for food in China today is rising incomes. What we suddenly have for the first time in history is 1.2 billion people trying to move up the food chain at a very rapid rate. When the United States was in a similar period of development some decades back, there were 200 million Americans. For Europe, it was 320 million, and for Japan it was 100 million. We're now looking at 1.2 billion people trying to do that, and doing it at a rate that is almost without precedent. Listen to these three numbers: 13%, 13%, 11%. Those are the rates of economic growth in China in 1992, 1993, and estimated for 1994. A phenomenal rate of growth for 1.2 billion people. Some of course are going up faster than that and some less, but on average this is a phenomenal advance.

So you begin to wonder what this means in terms of the demand for livestock products and therefore for grain. In China, there's no rangeland left to be developed. They can't turn to oceans in a major way for livestock products, so they can only get more livestock products or fish by feeding, basically grain.

Whenever you multiply anything by 1.2 billion, it's a lot. One more bottle of beer for each adult in China requires 370,000 tons of grain. In 1990, the average person in China was consuming 100 eggs per year. The official goal is to raise that to 200 eggs per person annually by the year 2000. Two hundred eggs per person, and by that time there'll be 1.3 billion people. That's 260 billion eggs. Getting from 100 eggs per person to 200 eggs per person will take more grain than Australia produces. So as China moves up the food chain, it's going to become an enormous sponge soaking up grain from all over the world. If we allow only for population growth and no gain in income and improvement in diet in China, by 2030 because of the absolute decline in agricultural production due to industrialization's use of cropland China will develop a deficit of about 200 million tons of grain, which compares with 28 million tons in Japan today. Two hundred million tons of grain equals total world grain exports from all countries. The United States accounts for about half of world grain exports, 100 million tons, and all other exporting countries—Canada, Australia, Argentina, Thailand—make up the other 100 million tons. But if, in addition, China continues to move up the food chain at the rate of recent years as incomes rise, it will need to import close to 400 million tons of grain.

This is not my calculation only. Professor Zhu-Guang Zhao, who is the head of the Chinese Academy of Sciences, has said, and I quote, "If we continue to squander our land and water resources in an all-out effort to industrialize, we will face the need to import 400 million tons of grain, and even all the grain produced in the United States will not be enough to fill that deficit."

This raises two questions. One, can China afford to import massive amounts of grain? The answer is yes. Last year, China's trade surplus with the United States alone was $23 billion. That was enough to import all the grain we exported last year to close to 100 countries. So the question is not so much can China afford to import; China is not Africa, which needs more grain but cannot afford to import it. The important question is who will supply China with that much grain, and the answer is no one. What this means is that the world grain market, which has been a buyers' market for the last four decades except for a brief period in the early' 70s, will become a sellers' market. The competition has been among the sellers for markets that never seem to be quite large enough. That will now change, and the competition will not be among the sellers, but among the importers for inadequate exportable supplies. And that means that instead of declining grain prices in real terms, which has been the case over the last four decades, there will be rising grain prices for as far as we can see into the future.

If I were writing a commodity newsletter and recommending purchases of futures, I would say that the first thing we should watch for is rising seafood prices. That's already occurring. Seafood prices are rising in real terms about 4% per year now for the world as a whole. The second thing I would watch is rice prices, because the producers of rice are faced not only with limited land supplies but also with severe constraints on the amount of fresh water that's available. Rice requires land and water. So rice prices will be the next to rise, and then after that wheat, and then the other grains. I think we're moving into an era that is very different from the one we've known since the middle of the century. Whether it's the seafood catch per person going down, or whether it's grain prices which I think will be rising in real terms—it's going to be quite different.

Now what if, in addition to China needing to move into the market in a major way to import grain, we also had some effect of global warming? Then we would have real chaos in world grain markets. What I think we will soon get from China when it announces plans to import large quantities of grain—which could come literally any year now if China continues to industrialize rapidly—is a wake-up call that will create sufficient economic instability in the world economy to convince even the doubters that the relationship between us, now 5.6 billion, and the environmental systems and resources on which we depend is in trouble. And we're going to have to address these issues in a major way. I think it will lead us to redefine security, recognizing that the real threat to our security in the future is not so much military aggression as it is growing human pressure on the Earth's natural systems and resources and the resultant deterioration of those systems, whether it's overfishing, deforestation, or soil erosion.

I think this redefinition of security will lead us to seriously consider reordering priorities, such as shifting resources out of military budgets and into expenditures for soil conservation, reforestation, family planning, investments in agricultural research, and so on. I think it will underline the importance of the plan of action that came out of the Cairo population conference, a plan of action that calls for bringing world population growth to a halt much sooner and at a much lower level than had earlier been considered—to between 8 and 10 billion by 2050, rather than to between 11 and 14 billion by the end of the next century. I think it's going to underline the need for national governments to do population carrying capacity assessments, to look at land resources, water resources, access to seafood, and the availability of technology to increase crop production, and begin to calculate how much food they'll be able to produce and relate it to the projected increases in population. And for many countries, I think this will lead to a rather dramatic shift in population policy.

The bottom line, if we're serious about stabilizing population and climate, is a restructuring of the global economy. At the Worldwatch Institute, we call this the Environmental Revolution. In scale, it is comparable to the Agricultural Revolution or the Industrial Revolution. The Agricultural Revolution led to an increase in population growth, altering population trends dramatically, and since then we've seen enormous growth. The Environmental Revolution, if it succeeds, will also lead to profound demographic changes in the form of a leveling off of world population growth, the reestablishment of the balance between births and deaths in the world. The Industrial Revolution was based on the shift to fossil fuels; the Environmental Revolution will be based on a shift away from fossil fuels. The other big difference is the pace. The Agricultural Revolution was spread out over 10,000 years. The Industrial Revolution began two centuries ago. But the Environmental Revolution, if it is to succeed, will have to be compressed into a few decades.

The Environmental Revolution will require leadership—strong, international leadership. And that's where Japan can play an important role. I don't think that most of you in Japan yet appreciate the economic role that you play in the world today. You are one of the world's leading trading countries. You are now the world's leading source of bilateral development assistance. If one looks at the international banks in the world today, private banks, the top 10 are all Japanese. Japan has a great deal of potential political influence in the world today related to the strength of its economy. I know that you think you're in an economic crisis now because the economy is not growing and hasn't grown for the last few years, and by Japanese standards I suppose that is a crisis. But the Japanese economy is a powerful economy, one based on a highly skilled, highly educated, hard-working labor force.

We need leadership in the population arena. No country is better suited to do this, simply because Japan itself faced a need to quickly slow population growth after the end of World War II. As an economy, you had lost access to the resources of Southeast Asia and China, and suddenly you had to rethink your future in terms of living on these resource-poor islands. And this led to a halving of the population growth rate between 1948 and 1955. In seven years, you reduced your population growth by half, and that's exactly what developing countries today need to do. We in the United States cannot provide that example, because we've never had that experience. You have. You can.

Another arena in which you can play a major role is in raising energy efficiency, a major contribution to climate stabilization along with the development of renewable energy resources. But Japan is a country that has led the way in increasing the efficiency of energy use and exporting these technologies. Helping developing countries use more energy-efficient technologies could be an important contribution to the eventual stabilization of climate. Similarly, with the development of renewable energy resources there's a real need to push ahead in developing wind power, geothermal power, and solar power in the form of photovoltaics, solar thermal power plants—a whole range of technologies moving very quickly where Japan could play a leadership role in development.

In conclusion, I would like to say thank you to the Asahi Glass Foundation for not only the Blue Planet Prize, which is in itself extraordinary, as Professor Seibold would agree, but also for the opportunity for the two of us to exchange ideas with you this afternoon. I would end by saying that I think Japan can play a far more important leadership role in the world today by fostering the Environmental Revolution—in leading it, if you will. This is because of the resources you have and the experiences that you have had. Again, thank you very much for this opportunity.

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Lester R. Brown

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Articles

Numerous articles in magazines and newspapers around the world.